NOTES ON THE ANATOMY OF NAUTILUS POMPILIUS.

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ATTACHMENTS OF THE MANTLE TO THE SHELL.

THE body of the Nautilus is held within its shell mainly by means of two large shell-muscles, which are attached to the shell at each side over large crescentic areas, nearer the dorsal than the ventral side of the animal. Between the ends of the muscles and the shell are thin plates of a chitinous substance which are sometimes spoken of as tendons. These tendons are light brown, and are composed of a large number of very thin layers. The long axis of the muscle attachment is directed dorso-ventrally.

The mantle also is attached to the shell along three separate lines, which extend between corresponding points of the shell-muscles. Huxley ('58) named these "aponeurotic bands." This general name I have found it convenient to retain, while naming each separate band according to its position as follows:

The dorsal aponeurotic band, extending between the dorsal ends of the shell-muscles over the dorsal surface of the body.

The anterior ventral aponeurotic band, extending between the ventral ends of the shell-muscles around the ventral surface of the body.

The posterior ventral aponeurotic band, extending between the dorsal ends of the shell-muscles around the ventral surface of the body, posterior to the anterior ventral band. Owen ('32) described the two first-mentioned bands, the dorsal and anterior ventral, and other writers have since noted them. Of the third band, the posterior ventral, I find no mention in any of the literature on the subject. Thin bands of the mate-

rial which exists between the ends of the muscles and the shell also extend along the aponeurotic bands. The posterior ventral band is narrower and more difficult to recognize than the others. Each band and muscle leaves a slight, though often distinct, mark upon the inner surface of the shell.

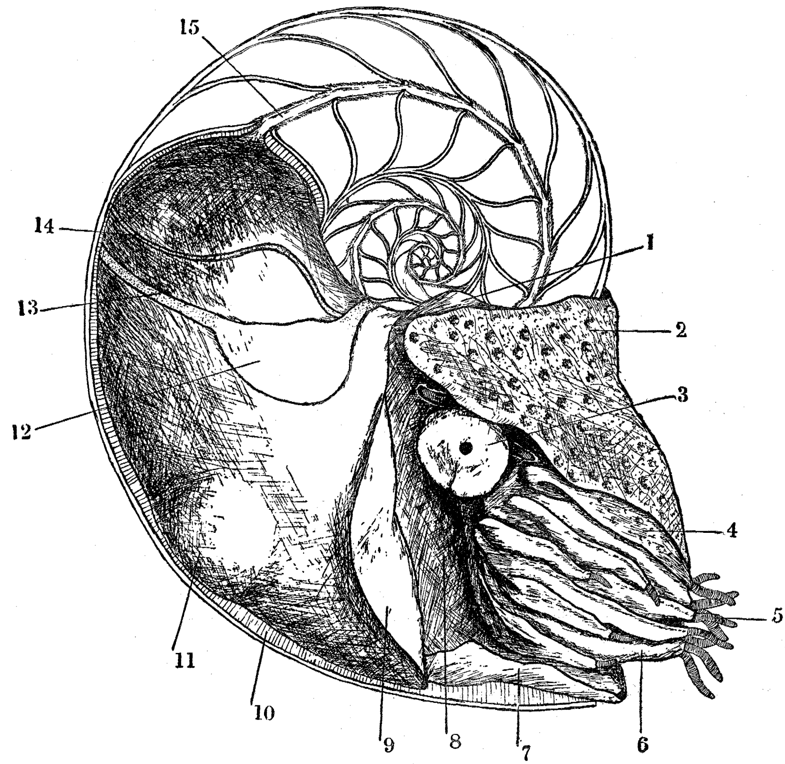

FIG. 1. — Nautilus pompilius, female. 1. Dorsal flap of mantle. 2. Hood. 3. Eye. 4. Second tentacle, showing papillated surface. 5. Cirrus of tentacle. 6. Tentacle forming sheath for cirrus. 7. Funnel. 8. Crus of funnel (M. collaris). 9. Reverted edge of mantle. 10. Occupied chamber of the shell. 11. Nidamental gland. 12. End of shell-muscle. 13. Anterior ventral aponeurotic band. 14. Posterior ventral aponeurotic band. 15. Siphuncle.

These attachments of the mantle to the shell can do little toward holding the Nautilus in its shell ; but they must be of the greatest importance by preventing water from passing between the mantle and shell to the siphon, thus penetrating the chambers and destroying the hydrostatic function of the shell.

Upon examining a large series of shells (more than one hundred) and the sixty-six specimens of Nautilus in the collection, I found that the dorsal and posterior ventral aponeurotic bands limit the formation of the septa. The entire area of the mantle posterior to these bands is active in the secretion of the lime forming the septa. But at the boundary formed by these bands the formation ceases. As the animal grows away from the last-formed septum the bands also move forward, maintaining a constant relation to the shell-muscles. A slight deposition of lime upon the inside of the shell extends forward from the edge of the septum to the above-mentioned limiting bands. It is evident that during what are called the resting periods of the Nautilus an intense secretory activity is maintained (at least in certain areas), and that during growing periods the secretion is very slight.

The Salivary Glands.

The presence of salivary glands in Nautilus has been considered doubtful. Near the œsophagus, upon the floor of the mouth, are two papillose processes, one at each side of the tongue. Owen ('**32**) described these as containing glandular cavities. Valenciennes ('**41**) more correctly described glandular bodies within the processes. From studies made upon serial sections of these glands I am convinced that they are true salivary glands, homologous, at least, with the anterior salivary glands of the Octopoda.

The glands are ovoid in shape, situated within the lower third of the processes. As a rule, each process contains but one gland ; in one case, in which serial sections were made of the process, an accessory gland was found opening beside the main gland. The glands are compound tubular, all the tubules being separated by septa of connective tissue which extend in from the body of the process, and all opening into a common central cavity. In some cases this cavity opens into the mouth cavity directly, while in others a very short duct leads from the gland to the mouth cavity. The opening of the duct into the mouth is upon the inner side of the process, somewhat below the center.

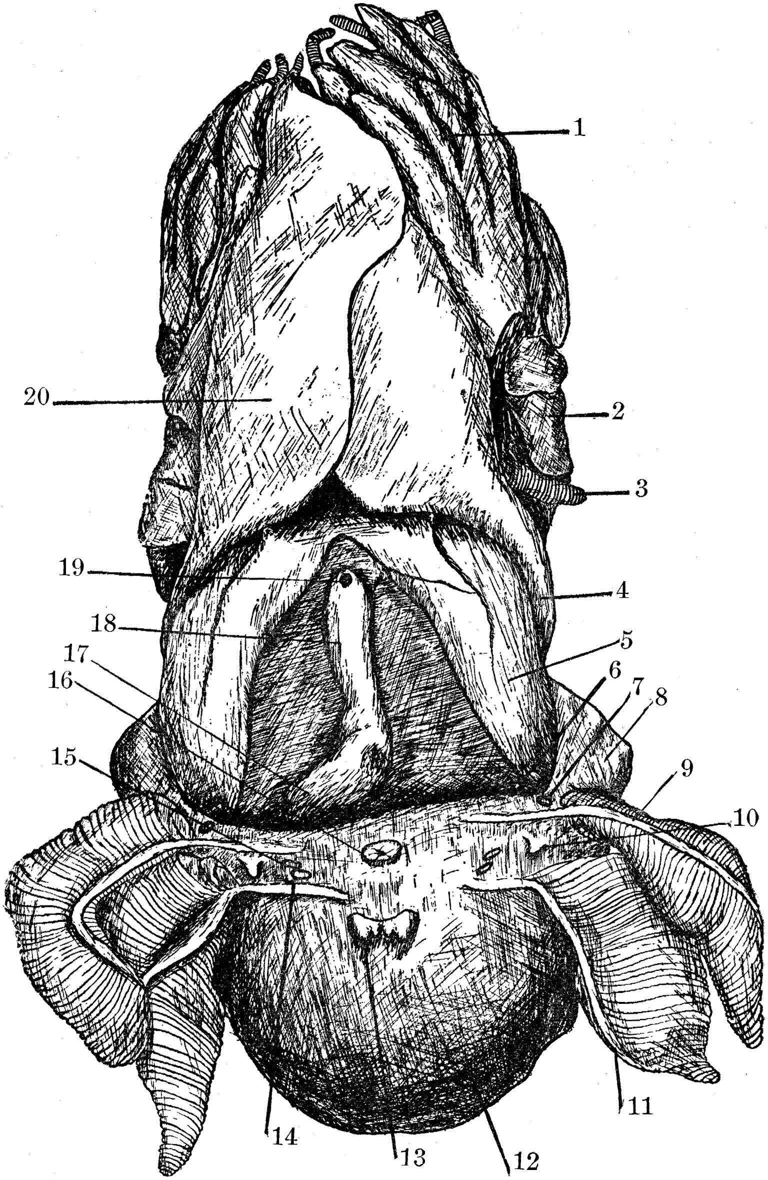

FIG. 2. — A male Nautilus pompilius seen from beneath, the mantle being folded back over the posterior portion of the body. 1. Tentacles. 2. Eye. 3. Infra-ocular tentacle. 4. M. collaris. 5. Shell-muscle. 6. Opening of the rudimentary reproductive organs of the left side. 7. Outer nephridial pore. 8. Mantle. 9. Branchial vein of superior gill. 10. Superior osphradium. 11. Inferior gill. 12. Mantle. 13. Inferior osphradium. 14. Inner nephridial pore. 15. Viscero-pericardial pore. 16. Anus. 17. Needham's sac. 18. Penis. 19. Opening of penis. 20. Funnel.

The tubules and the central cavity are lined by a columnar epithelium. The epithelial cells are very slender, their height being about twenty times the other diameters. Each cell contains an oval nucleus situated near its base.

The processes which contain the salivary glands are mainly composed of connective tissue through which run strands of longitudinal and longitudinally oblique muscle fibers. Blood lacunae penetrate the process. Toward the upper end of it the lacunae become so numerous that the connective tissue

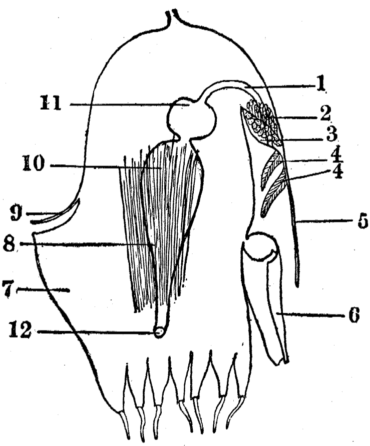

FIG. 3. — Diagram of Nautilus pompilius, modified from Lang. 1. Intestine. 2. Venous appendages. 3. Kidney chamber. 4, 4. Gills. 5. Mantle. 6. Funnel. 7. Hood. 8. Shell-muscle. 9. Dorsal flap of mantle. 10. Crop. 11. Gizzard. 12. Mouth.

forms merely a network around them. The processes are supplied with blood by an artery which comes from the buccal branch of the anterior aorta. There is no closed capillary system either in the salivary glands or in the processes. A nerve from the buccal ganglion accompanies the artery. The processes are clothed with a fine columnar epithelium.

The Otocyst.

The otocysts of Nautilus pompilius lie in hollows upon the front side of the cartilage to which the great muscles of the head and body are attached. They are situated one at each side, below and behind the junction of the cephalic, pedal, and pleural ganglia. The otocysts are ovate in form, and about

3.5 mm. in the direction of their long diameter. The end of the auditory nerve spreads out fan-wise upon their surfaces. The auditory nerve has its origin in the cerebral ganglion. In its course it passes over the pedal ganglion, where the sheaths of the nerve and the ganglion are so closely united as to make it appear that the nerve has its origin in the pedal ganglion.

The otoliths are white calcareous bodies, 2 mm. by 1½ mm. by 1 mm. These dimensions are average. In form, the otoliths are roughly ovate; though the shape varies to a slight extent, not always being exactly the same in the two otoliths of one Nautilus. Each otolith consists of an immense number of small elliptical crystals, solidly cemented together. The crystals vary in size from .0011 mm. to .0066 mm. in thickness, and in length from .0033 mm. to .014 mm. The crystals are composed of calcium carbonate, giving characteristic chemical and light reactions. They all have the shape which would be assumed by a perfect crystal of dog-tooth spar if all the angles were rounded. Very frequently cases of the twinning of two or more crystals are seen. In cases where two crystals are twinned the angle between their axes is usually 78°, any divergence from this angle being quite small, so far as observed. In cases of twinning the ends of each crystal are as perfect as in single crystals. These unions of several crystals form the cross and star-shaped bodies, "etc.," mentioned by Macdonald ('55). The bright points observed by Macdonald are seen only when the focal plane of the lens is above the plane of the crystal.

Macdonald seems to have been the only one who has dissected the otocysts of Nautilus. He dissected a fresh specimen of Nautilus umbilicatus, and was the first to rightly locate the otocysts of Nautilus. He, however, describes the otocyst as "filled with a cretaceous pulp consisting of minute, elliptical otokonia." As far as regards the "otokonia" I agree perfectly with Macdonald. But in every case in which I have dissected the otocyst of Nautilus pompilius I have found a single large otolith, and not in any case a cretaceous pulp. When this mass was boiled in concentrated solution of caustic

potash no change occurred, either in the shape of the mass or in its hardness. Drawings were made of the masses before treatment, and with these the masses were afterwards compared. But the crystals were broken down, according to the well-known action of caustic potash upon calcium carbonate. This experiment tends to prove that the crystals were not cemented together after the death of the Nautilus by the coagulation by alcohol of some fluid in which the crystals normally are immersed. Upon treating the masses with dilute sulphuric acid they were broken down, and characteristic crystals of selenite were formed. If these masses which I find in the otocysts were produced by coagulation processes they would neither be so regular in shape as they are, nor solid, but would abound in cavities filled with a coagulate. In only one case have I found any organic matter with these masses, and in this the quantity was very small and the material was found as a thin layer upon the outside of the mass. From these considerations I judge that the otolith of Nautilus pompilius is single.

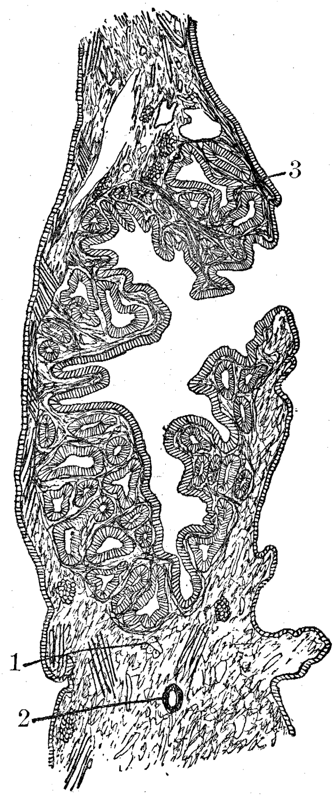

FIG. 4. — A section of the salivary gland of Nautilus pompilius. Outlined with the camera lucida.

THE PALLIAL COMPLEX.

The pallial complex of Nautilus pompilius presents several points in which it differs from that of other Cephalopoda. The mantle cavity extends completely around the body. It is deepest ventrally and shallowest at the sides, and about a third as deep dorsally as ventrally. The gills are four in number,

as are also the nephridia. The gills, moreover, are not situated upon the body wall, as in other Cephalopoda, but upon the inner side of the mantle-fold, near its junction with the body. If the mantle be split along the mid-ventral line it is plain that the gills hang from the mantle, while the sacs of the nephridia lie wholly within the mantle-fold ; a small portion of the posterior venous appendages hanging into the body cavity back of the mantle. The heart lies just back of the mantle-fold. The branchial veins run for some distance in the mantle-fold. The position of the venous appendages within

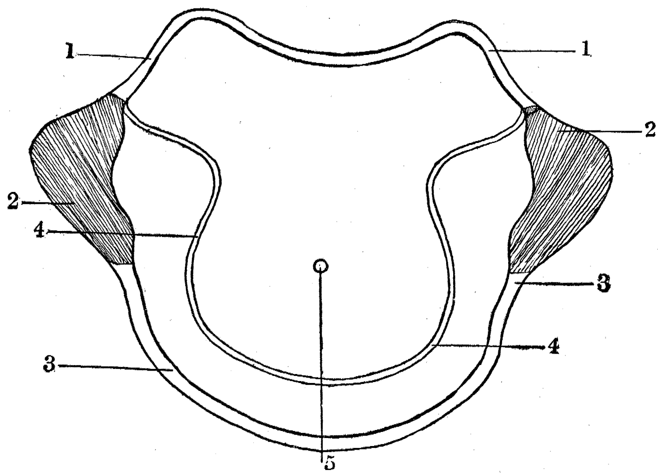

FIG. 5. — The lines of attachment of the mantle to the shell spread upon a flat surface. 1. Dorsal aponeurotic band. 2. End of shell-muscle. 3. Anterior ventral aponeurotic band. 4. Posterior ventral aponeurotic band. 5. Position of siphuncle.

the mantle-fold necessarily causes the posterior portion of the mantle to be very much thickened. Owing to this position of these organs the posterior part of the mantle-fold has also lost its musculature to a great extent. When the mantle is reverted these parts sink into the body cavity, and the gills appear to be situated upon the body wall. It is probably due to these conditions that previous observers have failed to see the true relations of the parts noted. The gills are, however, plainly situated upon the mantle, since they are at the sides of the nephridia, where the mantle is thin and very muscular.

The nephridial and pericardial openings, the anus, osphradia, and nidamental gland are also all upon the inner side of the mantle. The only parts of the pallial complex which are situated upon the body wall are the openings of the reproductive organs.

Thus there is in the Nautilus pompilius the same arrangement of the parts of the pallial complex as in many Gasteropoda. Opening in the median line upon the inner side of the mantle is the anus. Symmetrically disposed upon either side of the anus, also upon the inner side of the mantle, are the pericardial and nephridial pores, gills, and osphradia. Within the mantle, near its base, are the nephridia. The heart is close to the base of the mantle, but not within it. The reproductive openings, as in the Gasteropoda, are upon the body wall, one at each side of the body.

These relations of the parts of the pallial complex are very evident in all my specimens (sixty-six in all), and must be very much more distinct in living specimens, in which the mantle has not been shrunken by reagents. From the manner in which Huxley ('58) speaks of the positions of the nephridial pores, I judge that he recognized the same relation of the parts of the pallial complex which I have here.

In none of the papers listed in the bibliography at the end of this paper have I found mention of the points which I here note, and which seem important enough to justify publication in advance of a more extended account of the anatomy of Nautilus.

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